International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 747-758

PERFORMANCE ASSESSMENT OF AN AUTOMOBILE RADIATOR USING AL_2O_3/WATER+EG BASED NANOCOOLANT

CH. SURESH[1], C. L. V. R. S. V. PRASAD[2] & K. SANTA RAO[3]

[1]*Research Scholar, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India*

[2]*Professor, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India*

[3]*Assistant Professor, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India*

ABSTRACT

The traditional coolants like water, water blended propylene glycol or ethylene glycol were used in automobile radiators and they possess poor thermo physical properties. The best method for augmentation of heat transfer rate in automobile radiator is the usage of nanofluids as coolants. Nano fluids are the colloidal solutions prepared by diffusion of nanopowder into base fluid. In this paper, the heat transfer performance of Al_2O_3/Water+EG (volume=70:30) based nanofluids were experimentally investigated while used in an automobile radiator. All the experiments were conducted for different volumetric concentrations of 0.1-0.3% of nanofluids and different flow rates of 5-7 lit/min and various working temperatures ranging from 60°C - 90°C. Based on the results it was observed that radiators using nanofluids show better heat transfer performance when compared with the performance while using base fluid. The maximum enhancement in convective heat transfer coefficient of 41% was recorded with 0.3 vol% concentrations operating at 75°C of radiator inlet temperature and 7 lit/min flow rate when compared to base fluid.

***KEYWORDS**: Nanofluid, Nusselt Number, Thermal Conductivity & Heat Transfer Coefficient*

Received: Jun 10, 2018; **Accepted**: Jun 30, 2018; **Published**: Jul 27, 2018; **Paper Id.**: IJMPERDAUG201878

Original Article

1. INTRODUCTION

The radiator is a significant part in the automobiles, used to keep the engine coolant at desired temperatures by removing the heat from the coolant. In the earlier times, the conventional coolants like water, water blended PropyleneGlycol (PG) or Ethylene Glycol (EG) was most commonly used. To enhance the overall performance of engines, researchers started focusing on to maintain optimum engine temperatures which will have a predominant contribution. Maintenance of optimum engine temperature will further contribute to a reduction in fuel consumption and emissions also. These are indirectly achieved by augmentation of heat transfer rate in an automobile radiator. In the earlier days, the conventional methods fins and micro channels were used to improve the heat transfer rate, but these methods have limitations due to the physical constructional constraints. Therefore, researches started exploring new innovative methods which will improve the thermo-physical properties of traditional coolants rather than working on the constructional features of the heat exchangers. The conventional coolants mentioned earlier generally possess poor thermophysical properties. So, the heat transfer performance of such conventional coolants improved by dispersion of small solid particles, such as metal oxide and metallic particles into conventional fluids.

In fact, several theoretical and experimental studies have been conducted on the thermal performance of suspensions containing solid particles from Maxwell model (1881) [1]. However, all of those studies,

conventional fluids dispersed with a millimetre or micrometre-sized solid particles are used. Although the solid additives may enhance the heat transfer rate, practical application of such aggregates is limited because micrometre and millimeter-sized particles cause several problems such as quick settling, clog flow channels, erode pipelines and severe pressure drops [2]. Therefore, researchers are working with the above problems and found nano particles to be promising to deal with theabove-mentioned problems to a greater extent. Nanofluids are the new innovative heat carrier fluids which are prepared by dispersion of nanopowder (less than100nm) with conventional fluids, coined by Choi [3, 4] and they show better heat transfer performance compared to base fluids. Min-Sheng Liu et al. [5], experimentally examined thermal conductivity of EG/CuO nanofluids and observed 22.4% enhancement in the thermal conductivity compared to the base fluids with 5 Vol%. ChilamkurtiLvrsv Prasad et al. [6], experimentally studied heat transfer coefficient and the coefficient of friction of lubricants blended with Al_2O_3 nanopowder and observed 46.35% increase in heat transfer coefficient and 16.85% reduction in coefficient of friction at room temperature (35°C) with 0.5Vol%. K. Y. Leong et al. [7], conducted the experiments on car radiator using EG/Cu nanofluids with 0-2 Vol% range and observed that 3.8% of improvement in the heat transfer rate with the dispersion of 2% Cu nanopowder with Reynolds number of 5000 and 6000 for coolant and air respectively. Durgeshkumar Chavan et al. [8], investigated heat transfer characteristics of Al_2O_3/water based nanofluids in an automobile radiator with 0-1 Vol% and the flow rates of 3-5 l/min. They concluded that the maximum improvement in heat transfer coefficient up to 40-45% was recorded with 1 Vol%. Rahul A. Bhogare et al. [9], experimentally studied the thermal performance of Al_2O_3/ water-EG nanofluids in a car radiator with 0-1 Vol%. They conducted the experiments with varying the air side Reynolds number from 83491-91290. The maximum enhancement in effectiveness and heat transfer were recorded to be 54% and 3.8% at 1 Vol% and 83491 air side Reynolds number. N. A. Usri et al. [10], performed the experiments on an automotive cooling system using Tio_2/water-EG (water-EG = 60:40 by volume) nanofluids. The experiments were conducted with the Reynolds number more than 10000 (turbulence region) and with the volumetric concentrations of 1.0% and 1.5 %. The maximum enhancement in convective heat transfer coefficient is recorded as 33.9% at 1.5 Vol% compared to base fluids. Hafiz Muhammad Ali et al. [11], studied heat transfer performance of ZnO/water based nanofluid in a car radiator. The experiments were performed within the volume fractions of 0.01-0.3 Vol%, flow rates of 7-11 l/min and the temperature between 45℃-55℃. Compared to base fluids, nanofluid enhances heat transfer rate up to 46% with 0.2 Vol%. Devireddy Sandhya et al. [12], experimentally examined heat transfer characteristics of TiO_2/water-EG based nanofluids with 0.1-0.5 Vol%. The experiments were performed with the Reynolds number of 4000 to 15000. The highest improvement in convective heat transfer coefficient (CHTC) is reported as 35% with 0.5 Vol%. C. Selvam et al. [13], experimentally studied heat transfer performance of an automobile radiator with graphene nanoplatelets based coolant at volume fractions of 0.1-0.5% and the nanofluid flow rates of 12.5g/s-62.5g/s. They also varied ambient air velocity and the nanofluid inlet temperatures from 1-5 m/s and 35℃ to 45℃ respectively. The results stated that the OCHTC enhanced up to 104% at 0.5% volume fraction, 62.5g/s flow rate and at an ambient air velocity of 5 m/sin comparison with the base fluids.

In the present work, all the experiments were performed to study the effectiveness of an automobile radiator using Al_2O_3/water-EG (H_2O:EG = 70:30 by volume) nanofluid as a coolant. The experiments were conducted using nanofluids having 0.1-0.3vol%concentration, flow rates vary from 5-7 lit/min and the radiator inlet temperatures varying from 60℃-90℃. Till now no work has been reported usage of the magnetic stirrer during the experiments. In this work, a magnetic stirrer, which was placed on the bottom of the storage tank for the continuous stirring of the working fluid during the experimentation, has been used to avoid sedimentation of nanoparticles and maintain the stability of the

nanofluid.

2. NANOFLUIDS PREPARATION

In the current research work, the base fluid is a mixed solution of water/EG (H_2O: EG = 70:30 by volume) and nanofluids were prepared by suspension of Al_2O_3 nano particles into the base fluids. In general, nanofluids are prepared by two methods [14]: the first one is a single step process and the other is a two-step process. In the single step process preparation of the nanoparticles along with dispersing those into base fluid take place simultaneously. In two-step process initially the nanoparticles are prepared by using different methods and later nanoparticles were diffused with the base fluids. The two-step process is more economical and flexible. Thus, in this investigation two-step method was used to prepare the nanofluids and Al_2O_3 nanoparticles that were used, have the physical properties as listed in the Table1.

$$\text{Volume concentration } (\varphi) = \frac{\frac{w_{particle}}{\rho_{particle}}}{\frac{w_{particle}}{\rho_{particle}} + \frac{w_{fluid}}{\rho_{fluid}}} x100 \quad (1)$$

Where w=mass (kg), ρ= density (kg/m^3). Initially, the quantity of nanopowder needed to prepare each sample of the nanofluid was determined by using the above formula. Then the measured amount of the nanopowder was directly added to base fluid after that, the sample is placed on the magnetic stirrer (Remi 2MLH model) for one hour to dissolve the nanopowder inside the base fluid. Then the prepared solution was kept in ultrasonicator (frequency: 20KHz and power:1000W) for 30 minutes to uniform dispersion and deagglomeration of the nanoparticles in the base fluid. Such a way, various concentrations (0.1,0.2,0.3 Vol%) of nanofluids were prepared. Figure1 shows the nanofluids preparation by a two-step process. Preparation of the homogeneous and stable nanofluid is the most important factor, otherwise which will severely influence heat transfer characteristics of nanofluids. Nanofluids are generally stabilized by adding surfactants or stabilizers, which affects the thermal characteristics of the nanofluids [15]. Therefore in the present work, no surfactants were used to stabilize the nanofluid. However, the stability of the nanofluid was ensured by the dynamic motion of nanofluid in the storage tank; the motion of nanofluid was created by using magnetic stirrer placed on the bottom of the tank to maintain the steadiness of the nanoparticles inside the basefluid without any chance of sedimentation. And further, nanofluids passing through the channels remain stable due to their continuous motion.

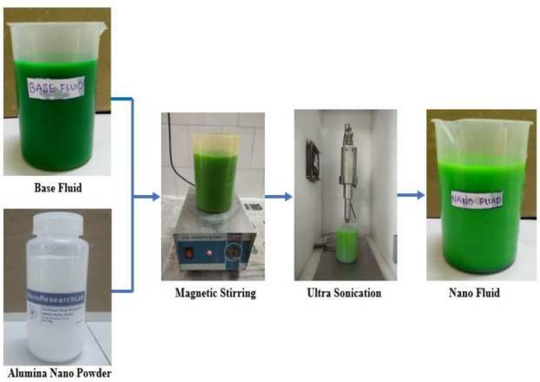

Figure 1: Nanofluids Preparation by a Two-Step Method

Table 1: The Properties of Alumina (Al_2O_3) Nanopowder

Specification	Value
Appearance	white powder
Purity	99.5%
True density	3.97 g/cm^3
SSA	120-140 m^2/g
Average particle size	30-50 nm
Morphology	Spherical
Thermal Conductivity	31.922 W/m K
Specific heat	873.336 J/kg K

3. EXPERIMENTAL SETUP

Figure 2 shows the schematic illustration and the experimental test rig setup. The experimental set up includes Pipelines, Storage tank, Centrifugal pump, Automobile radiator, Temperature indicator, Forced draft fan, Magnetic stirrer, Thermostat, Heater and Thermocouples. In all the experiments the working fluid is filled up to 33% of the storage tank. The automobile radiator used in our research is Maruti Alto 800 model, it consists of 48 number of capsule cross-sectional shaped vertical tubes, made of aluminiumand the specifications of the automobile radiator are listed in Table2.

Table 2: Specifications of the Automobile Radiator

Tube length	38cm
Tube width	1.1cm
Tube thickness	0.5 mm
The radius of a semicircle of the tube	0.15cm
Total number of the tubes	48
Total surface area	0.5731 m
Hydraulic mean diameter	0.0051009 m

To conduct experiments at different temperatures, nanofluid is heated by a 3 KW Electrical heater which has a thermostat based temperature controlling system. To measure the temperatures across the radiator, total 12 thermocouples (J type) werefixed. Three thermocouples are used to monitorthe radiator inlet, outlet and reservoir temperatures and the remaining nine thermocouples are used to indicate the radiator tubes outside the wall temperatures. In the current research work, more focus is on liquid side heat transfer coefficient, which can be determined through the inside wall temperatures. However, the inside tube wall temperature is presumed to be equivalent to the external surface wall temperature as the thickness radiator tube wall is negligibly small. All the experimentations were performed by varying the radiator inlet temperature and the flow rate varying between 60-90°C and 5-7 l/min respectively.

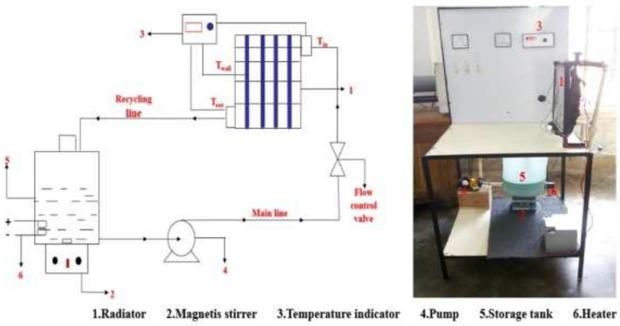

Figure 2: Schematic Illustration and Picture of the Experimental Test Rig

4. DATA PROCESSING

4.1. Measurement of Nanofluid Thermophysical Properties

Nanofluids are the colloidal solutions in which alumina nanopowder is suspended into the base fluid. Before measuring the thermophysical properties, uniform suspension of the nanoparticles in the base fluid is to be ensured. Some classical equations are suggested by pak and cho et. al are utilized for assessment of the properties of the two-phase fluids [15]. The following equations were used for calculating thermal conductivity, specific heat, viscosity and the density of the nanofluids.

$$\rho_{nf} = \varphi \rho_{np} + (1\text{-}\varphi)\rho_{bf} \tag{2}$$

$$C_{p_{nf}} = (1\text{-}\varphi)\left(\frac{\rho_{bf}}{\rho_{nf}}\right) c_{p_{bf}} + \varphi\left(\frac{\rho_{np}}{\rho_{nf}}\right) c_{p_{np}} \tag{3}$$

$$\mu_{nf} = \mu_{bf}(1+2.5\varphi) \tag{4}$$

$$K_{nf} = \frac{K_{np}+(n-1)K_{bf}-\varphi(n-1)(K_{bf}-K_{np})}{K_{np}+(n-1)K_{bf}+\varphi(K_{bf}-K_{np})} K_{bf} \tag{5}$$

Where n $=\frac{3}{\emptyset}$ and subscripts nf=nanofluid, np= nanoparticle and bf=base fluid.

$\emptyset$ is the particle sphericity, defined as the ratio of surface area of the sphere with a volume equivalent to nanoparticle volume and surface area of the nanoparticle. In this research, it was assumed that the nanoparticles are in a spherical shape and hence particle sphericity of 1 is considered

4.2. Estimation of Coolant Side Convective Heat Transfer Coefficient

Based on Newton's Law of Cooling the heat transfer rate is expressed as:

$$Q = h\ A(T_b\text{-}T_w) \tag{6}$$

Further, the heat transfer rate is also evaluated as following:

$$Q = \dot{m}c_p\Delta T = \dot{m}c_p\,(T_{in}-T_{out}) \tag{7}$$

$$Nu_{Exp} = \frac{h_{exp}D}{k} = \frac{\frac{\dot{m}c_p(T_{in}-T_{out})}{A(T_b-T_w)}D}{K} \tag{8}$$

Where D = $\frac{4\,A_c}{p}$ and subscripts b=bulk mean, w= wall

Following is the nomenclature and all the thermophysical properties are determined at bulk mean temperature of the nanofluid:

$\dot{m}$: mass flowrate (kg/s); c_p: specific heat at constant pressure of the fluid (J/kg k); A: Total surface area of heat transfer (m^2); k : Thermal conductivity of the working fluid (w/mk); D: Hydraulic mean diameter (m); A_c: Cross-sectional

area (m^2); p: Perimeter of the radiator tubes(m); h: Average convective heat transfer coefficient (w/m^2k); T_{in}&T_{out}: Radiator inlet and outlet temperatures; T_b,: Bulk mean temperature obtained by an average of the radiator inlet and outlet temperatures; T_w: Mean wall temperature obtained from the average of the nine radiator surface wall temperatures; Nu_{EXP}: Average nusselt number.

5. RESULTS AND DISCUSSIONS

5.1. Base Fluid

Before performing the experiments with nanocoolants, the experiments were conducted with the base fluid (Water+EG) to validate the experimental test rig. Figure 3 indicates the experimental outcomes at constant radiator inlet temperature of 80°C. Based on the results it was observed an increase in nusselt number with the increment of Reynolds number. Also, the experimental data was compared with theoretical data calculated from Dittus-Boelter correlation [16] (Eq.9) and Gnielinsky correlation [17] (Eq.10) for single phase fluids to validate the test rig.

$$Nu(th) = 0.0236\ Re^{0.8}\ Pr^{0.3} \tag{9}$$

$$Nu\ (th) = \frac{\frac{f}{8}(Re-1000)Pr}{1+12.7\left[\frac{f}{8}\right]^{0.5}(Pr^{\frac{2}{3}}-1)} \tag{10}$$

where f = (ln Re -1.69)$^{-2}$

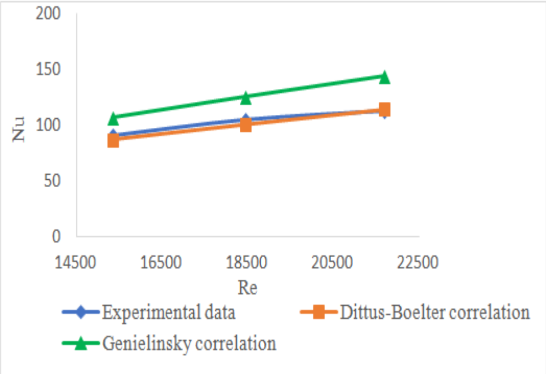

Figure 3: Comparison of the Experimental Data with Theoretical Data

Based on the above plots it was observed that the experimental data are in agreement with the theoretical data obtained from Dittus – Boelter correlation with a maximum error of 5 %. Then the consistency of the experimental test rig and calculated data need to be confirmed.

5.2. Nanofluids

Using the nanofluids prepared at different volumetric concentrations (0.1%-0.3%), for each concentration the nanofluid was circulated at various flow rates (5-7 lit/min) and temperatures (60°C-90°C) through the radiator tubes. When the nanofluid passes through the radiator, convection mode of heat transfer takes place between the nanofluids and radiator walls, and then the heat absorbed by the radiator walls will be rejected to the atmosphere through the forced convection using a draft fan.

Figure 4 indicates the variation of Nu_{Exp} for the various flow rates of working fluid. The results depict the enhancement in Nu with increasing the volumetric concentration of the nanoparticles and increasing the flow rate of the working fluid. The increment in flow rate intensifies the turbulence of the working fluid in the radiator causing better mixing of nanoparticles thereby producing a homogeneous stable nanofluid. This in turn enhances the Nu leading to enhancement of the convective heat transfer coefficient. At 0.3 vol%, 33% enhancement in Nu was observed at 7 lit/min and 80°C of radiator inlet temperature compared to the same nanofluid at 5lit/min. While dispersion of 0.3 vol% to the base fluid, 38% augmentation in Nu was recorded at 80°C of radiator inlet temperature compared to base fluid at 7 lit/min. This same phenomenon we observed at all the flow rates and the temperatures of the working fluid.

In order to know the thermal performance of an automobile radiator the experiments were performed at various temperatures from 60°C-90°C. Figure 5 indicates the nusselt number variation with the radiator inlet temperatures. Based on the results improvement in nusselt number is observed with the increasing working fluid temperatures. The same trend is observed for all the concentrations of nanofluids. At 0.3 vol% concentration 21% improvement in Nu was recorded with varying working fluid temperatures between 60°C-90°C with the flow rate at 7 l/min.

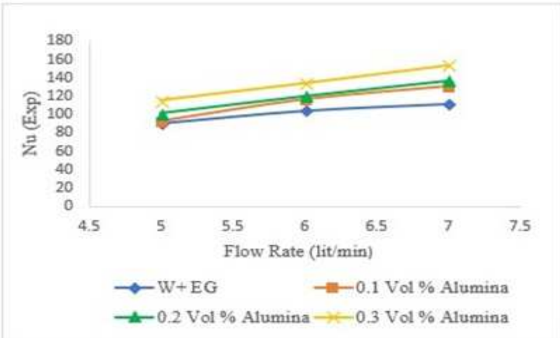

Figure 4: Nusselt Number Variations of Nanofluids with the Flow Rate at 80°C

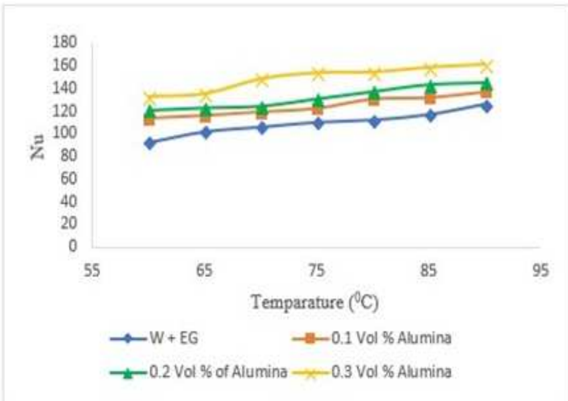

Figure 5: Nusselt Number Variations of Nanofluids with Radiator Inlet Temperatures at 7 lit/min

Thermal conductivity plays an important role in the enhancement of heat transfer coefficient. The following are the reasons for the enhancement of thermal conductivity,

- Thermal conductivity of both the base fluid and nanoparticle,
- Effective surface area for heat diffusion,
- Brownian Movement of the nanoparticles inside the base fluid.

Figure 6 indicates thermal conductivity variation with the concentration of nanoparticles. Based on the results it was observed that increase in thermal conductivity of the nanofluids with the increasing volumetric concentration of nanopowder. While increasing the concentration, a large number of particles was participated in the heat transfer indicating that the total effective surface area was increased for heat transfer. Hence it was reported that 0.78% enhancement in thermal conductivity which consequently enhances the heat transfer coefficient with 0.3 Vol% concentration of nanofluid compared to base fluid.

Figure 7 indicates thermal conductivity variation of nanofluids with the working fluid inlet temperatures. The results depict an improvement in nanofluids thermal conductivity with increasing the working fluid temperature. Increase in the nanofluids temperature rises the movement of the particles within the base fluid so that enhancement in thermal conductivity is recorded. At 0.3 Vol%, 3% enhancement in thermal conductivity was reported with the increasing working fluid temperatures between 60°C-90°C.

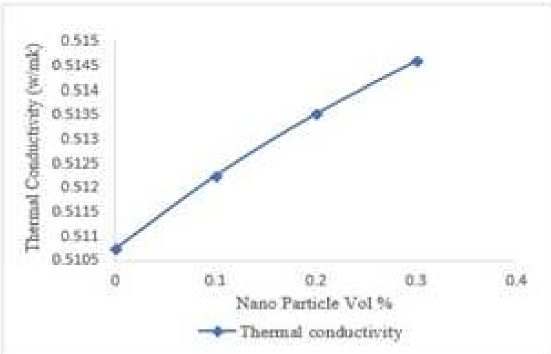

Figure 6: Variation of Thermal Conductivity of Nanofluids with Different Volume Fractions at 80°C and 7 lit/min

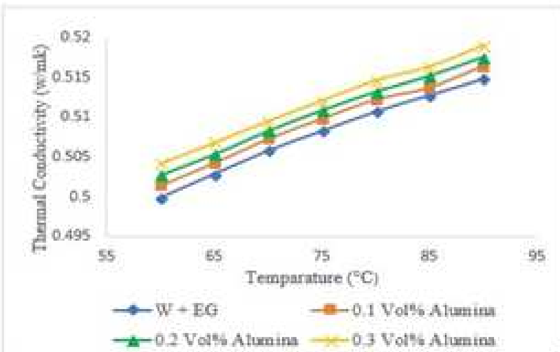

Figure 7: Variation of Nanofluids Thermal Conductivity with Working Fluid Temperatures at 7lit/min

Figure 8 indicates dynamic viscosity of nanofluids variation with the volumetric concentration of nanopowder. The results stated that dynamic viscosity of the nanofluids increases with the increasing concentration of nanopowder. Increasing the concentration of nanoparticles rises the resistance to movement of the fluid. Accordingly, an enhancement in the dynamic viscosity is observed. In comparison with the base fluid, 2% of enhancement in dynamic viscosity was recorded with 0.3 Vol%.

Figure 9 indicates dynamic viscosity of nanofluids variation with the working fluid temperatures. The results stated that the nanofluids dynamic viscosity decreases with the increasing working fluid temperatures. Enhancing the temperature of nanofluids causes more movement of the molecules leading to the high molecular motion which in turn reduces the flow resistance and consequently reducing the dynamic viscosity of the nanofluids. At 0.3 Vol%, 31% reduction in dynamic viscosity was reported with the increasing working fluid temperatures between 60°C-90°C.

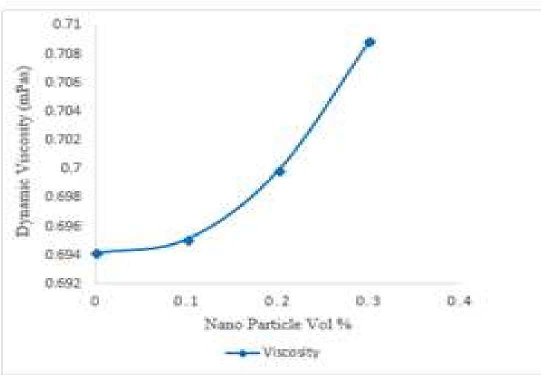

Figure 8: Dynamic Viscosity of Nanofluids Variation with Different Volume Concentrations at 80°C and 7 lit/min

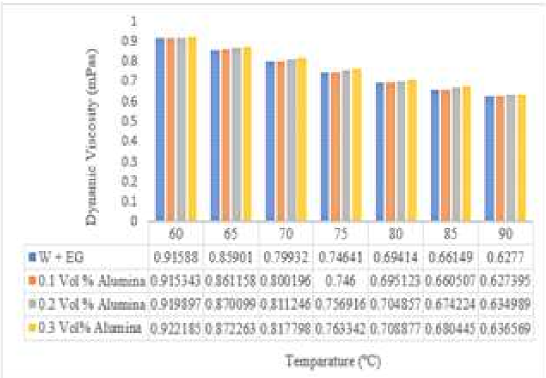

Figure 9: Dynamic Viscosity of Nanofluids Variation with the Working Fluid Temperatures at 7lit/min

The results show, compared to the base fluid, nanofluids show better heat transfer performance. Adding nanoparticles to the engine coolant enhances the heat transfer rate. So, for a given amount of cooling required the size of the radiator can be reduced. Reducing the size of the radiator, there is a decrease in the overall weight and size of the car. Then the load (frictional drag) acting on the automobile will be reduced which will contribute to the reduction of the fuel consumption and emissions.

6. CONCLUSIONS

In the current investigations, the performance of an automobile radiator using Al_2O_3/ water+EG based nanofluids is experimentally investigated. The results stated that nanofluids indicate better heat transfer performance compared to base fluids. The experimental results show that Nu increases in increasing the volumetric concentration of nanoparticles and increasing fluid flow rate. A maximum of 41% enhancement in Nu was recorded with 0.3 vol% and 75°C of radiator inlet temperature with 7 lit/min flow rate. The results also state that the nusselt number increases with the rise of radiator inlet temperature. Dynamic viscosity and Thermal conductivity of nanofluids were increased with the increase of the volumetric concentration of nanoparticles. Brownian Movement of nanoparticles is also an important factor that influences the heat carrying capacity of the nanofluid. The above results motivate the design engineers to develop compact and efficient radiators for automobiles.

REFERENCES

1. *Lee, S., Choi, S. S., Li, S. A., & Eastman, J. A.* (1999). *Measuring thermal conductivity of fluids containing oxide nanoparticles. Journal of Heat transfer, 121*(*2*), *280-289*.
2. *Mirmohammadi, S. A.,* &*Behi, M*. (2012). *Investigation on Thermal Conductivity, Viscosity and Stability of Nanofluids*.
3. *Choi, S. U.,* & *Eastman, J. A*. (1995). *Enhancing thermal conductivity of fluids with nanoparticles (No. ANL/MSD/CP--84938; CONF-951135--29). Argonne National Lab., IL (United States).*
4. *Akhilesh, M., Santarao, K.,* &*Babu, M. V. S.* (2018). *Thermal Conductivity of CNT-Wated Nanofluids: a Review. Mechanics and Mechanical Engineering, 22*(*1*), *207-220*.
5. *Liu, M. S., Lin, M. C., Huang, I. T.,* & *Wang, C. C.* (2006). *Enhancement of thermal conductivity with CuO for nanofluids. Chemical engineering & technology, 29*(1), *72-77*.
6. *Chilamkurti, L. P., Rao, I. D.,* &*Santarao, K*. (2017, *November*). *Experimental Investigations to Study the Effect on Coefficient of Friction and Heat Transfer Coefficient in the Lubricants with Nano Blending. In ASME 2017 International Mechanical Engineering Congress and Exposition (pp. V008T10A088-V008T10A088). American Society of Mechanical Engineers.*
7. *Leong, K. Y., Saidur, R., Kazi, S. N.,* & *Mamun, A. H.* (2010). *Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator). Applied Thermal Engineering, 30*(*17-18*), *2685-2692*.
8. *Chavan, D.,* &*Pise, A. T.* (2014). *Performance investigation of an automotive car radiator operated with nanofluid as a coolant. Journal of Thermal Science and Engineering Applications, 6*(*2*), *021010*.
9. *BhogareÁ, R. A., Kothawale, B. S., Bodkhe, P. P.,* &*Gawali, A.* (2014). *Performance investigation of Automobile Radiator operated with Nanofluids Based Coolant. International Journal of Thermal Technologies E-ISSN, 4*(*2*), *2277-4114*.
10. *KM, Subbaiah*, et al. "*Foam Finned Down Flow Type Automotive Radiator Rating and Sizing*." (2016).
11. *Usri, N. A., Azmi, W. H., Mamat, R.,* & *Hamid, K. A.* (2015). *Forced convection heat transfer using water-ethylene glycol (60: 40) based nanofluids in automotive cooling system. International Journal of Automotive and Mechanical Engineering, 11, 2747*.
12. *Ali, H. M., Ali, H., Liaquat, H., Maqsood, H. T. B.,* & *Nadir, M. A.* (2015). *Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids. Energy, 84, 317-324*.

13. *Devireddy, S., Mekala, C. S. R., &Veeredhi, V. R.* (2016). *Improving the cooling performance of automobile radiator with ethylene glycol water based TiO2 nanofluids. International Communications in Heat and Mass Transfer, 78, 121-126.*

14. *Selvam, C., Raja, R. S., Lal, D. M., & Harish, S.* (2017). *Overall heat transfer coefficient improvement of an automobile radiator with graphenebased suspensions. International Journal of Heat and Mass Transfer, 115, 580-588.*

15. *Yu, W., &Xie, H.* (2012). *A review on nanofluids: preparation, stability mechanisms, and applications. Journal of nanomaterials*, 2012, *1*.

16. *Pak, B. C., & Cho, Y. I.* (1998). *Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Experimental Heat Transfer an International Journal, 11(2), 151-170.*

17. *Dittus, F. W., & Boelter, L. M. K.* (1985). *Heat transfer in automobile radiators of the tubular type. International Communications in Heat and Mass Transfer, 12(1), 3-22.*

18. *Gnielinski, V.* (1976). *New equations for heat and mass transfer in turbulent pipe and channel flow. Int. Chem. Eng., 16(2), 359-368.*